

Semi-annual Eos Contract Report -- Report #6

Period: January 15 - June 30, 1992

Remote Sensing Group (RSG),
Optical Sciences Center (OSC) at the University of Arizona

Principal Investigator: P. N. Slater

Contract Number: NAS5-31717

Report compiled by: K. J. Thome

INTRODUCTION: This report contains eight sections. Each section presents a different aspect of work performed under our contract. If appropriate, each section covers five areas; task objective, work accomplished, data/analysis/interpretations, anticipated future actions, problems/corrective actions. The eight sections are: 1) Science team support activities; 2) Cross-calibration radiometer; 3) Reflectomobile; 4) Shortwave infrared (SWIR) radiometer; 5) Bi-directional reflectance distribution function (BRDF) meter; 6) Cary spectrophotometer; 7) Algorithm and code development; and 8) Field experiments.

SCIENCE TEAM SUPPORT ACTIVITIES: This section refers to all work performed in support of MODIS and ASTER team activities as well as work performed for other sensor teams. Over the past six months this included the attendance at team meetings, signal to noise ratio (SNR) calculations for ASTER, MODIS filter studies, and support for MISR.

S. F. Biggar and P. N. Slater attended the ASTER Team meeting January 20-23 in Pasadena, California; the Cal-Val meeting in Boulder, Colorado, April 6-10; and the MODIS Science Team meeting in Washington, D. C., April 13-17. Slater presented SWIR SNR results as a function of aperture and gain at the ASTER Team meeting, and Biggar presented details of the cross-calibration radiometer at all three. Slater also attended the ASTER Team meeting in Japan, June 21-26.

Slater performed calculations of SNR for the visible and near infrared (VNIR) and SWIR cameras of ASTER. He used new quantum efficiencies supplied by Mitsubishi Electric Company (MELCO) and presented these SNRs for consideration at the Accommodation meeting the week of January 27. Biggar and Slater reviewed SNRs with Drs. Fujisada, Yakawa, and Watanabe on their visit to the University of Arizona the beginning of May. The two also reviewed the 34-page ASTER Calibration Requirement Document and telefaxed 11 pages of comments to Dr. A. Ono.

Following the June 1992 ASTER Science Team meeting, Slater recalculated the SWIR SNRs for all the gains presented by Dr. Fujisada and MELCO and for the latest values of array spectral

quantum efficiencies, QEs, and system spectral transmittances. (Slater points out that MELCO have presented at least five sets of QEs in the last six months and therefore that the values used here are not likely to be those for the flight system. He anticipates that, for this and several other reasons, his calculated SNRs may only be within $\pm 20\%$ of those of the flight system, although the relative changes of SNR with gain will be more precise, perhaps within $\pm 5\%$). Slater's graphs of SNR versus ground reflectance are shown in Figure 1; he blacked out the detector characteristics at MELCO's request. He concludes that a gain greater than unity only increases the SNR significantly for the 1.65 micrometer band and, in that case, little improvement is achieved by increasing the gain from 2 to 3 times, while there is a 33% reduction in dynamic range. Volcanologists should select between the lower gains, based on SNR and dynamic range considerations. Slater points out that the nearly straight-line relationships may be extrapolated to the maximum SNR for unity gain, to determine the SNRs for thermal sites whose radiances are greater than the solar-reflected-unity-reflectance radiances on the abscissa.

D. E. Flittner, P. N. Slater, and K. J. Thome examined proposed modifications to MODIS filters specifications. Flittner and Slater e-mailed comments and recommendations regarding bandpass modifications to members of the MODIS technical and science teams. Slater sent resampled Kitt peak data to S. Pellicori, consultant to Santa Barbara Research Company (SBRC), as well as the Flittner and Slater paper entitled "Stability of narrow band filter radiometers in the solar reflective range," (PE and RS, 1991, Vol. 57, pp 165-171). Thome e-mailed and telefaxed this same information to T. Pagano of SBRC and B. Grant at GSFC.

Slater and Thome analyzed changes in band-averaged solar irradiance for the MODIS visible and SWIR filters due to shifts in their central wavelengths and changes in bandpasses. An example of this work is shown in Fig. 2 and represent results for band 10 of MODIS. The original specifications for this filter were a central wavelength of 490 nm with a tolerance of 1.0 nm and a bandpass of 10.0 nm with a tolerance of 1.2 nm. SBRC sought relief from these specifications to increase the wavelength tolerance to 1.2 nm and the bandpass tolerance to 1.7 nm. The first plot indicates the percentage change in band-averaged solar irradiance for three filter bandpasses, a shift of 1.2 nm toward the blue end of the spectrum, and a range of central wavelengths between 475 and 505 nm. By studying this curve and a similar plot for a 1.2 nm shift to the red, we determined that it would be advisable to move the nominal central wavelength to 488 nm. The percentage change of band-averaged solar irradiance as a function of central wavelength shift for this wavelength is given in the lower graph. Note that in this case, the relief sought by SBRC was acceptable. Similar work was performed for bands 1-19 of MODIS. Slater and Thome sent the results of these studies to H. Gordon, B. Grant, W. Barnes, J. Harnden, and M. King. Thome also discussed the results with A. Huete.

Biggar provided support to C. Bruegge of the Multi-angle Imaging Spectroradiometer (MISR) calibration team by performing preliminary measurements of directional reflectance of a Spectralon sample sent by Bruegge. Labsphere manufactured the sample and JPL coated it with indium tin oxide to reduce static charge buildup. Biggar compared results to those from an uncoated Spectralon sample from Labsphere and a pressed Halon sample made in our laboratory. He determined the Spectralon samples were neither flat nor of constant thickness, making it difficult to reliably measure directional reflectance. Preliminary results indicate the coating enhances the specular reflection, making the coated Spectralon less lambertian.

CROSS-CALIBRATION RADIOMETER: The task objective of this project is to design and build a 400 to 1000 nm cross-calibration radiometer, test this radiometer, and write control and data acquisition software. This radiometer will provide an independent calibration and cross-calibration of radiance sources used by Phase C/D contractors.

Biggar designed the radiometer with three silicon detectors in a "trap" configuration. Spectral selection is through interference filters selected by manually turning a filter wheel. Two precision apertures, separated by dimensionally stable invar rods, determine the throughput. Biggar selected a low noise transimpedance amplifier configuration with a FET type operational amplifier and selectable gain. Heating the detector assembly, filters, apertures, and amplifier to a stabilized temperature a few degrees above ambient provides thermal control of the system. A commercial datalogger will digitize the amplifier output and ancillary information such as detector temperature. This datalogger will send the output to a MS-DOS compatible computer. The entire radiometer consists of the head with filter wheel, electronics/power supply package, connecting cables, datalogger, and computer.

Biggar began construction of the radiometer. OSC machine shop personnel machined all mechanical parts using drawings provided by Biggar. All parts except the invar rod were oxide blackened. He purchased the datalogger, detectors, and heaters, and ordered the filter wheel, platinum resistance thermometers, vacuum compatible thermal adhesive, amplifiers, feedback resistors, main power supply, and capacitors for the amplifiers. Biggar also performed a preliminary analysis of the radiometers characteristics yielding the following:

Full FOV:	2.3	degrees
Vignetted FOV:	4.6	degrees
Projected FOV:	4.4	cm at 50 cm
Bandpass:	0.02	micrometers
Dark Noise:	0.18	microvolts
Input Radiance:	342	W/m**2-micrometers-sr (at 0.6 micrometers)
Signal	3.68	volt

Biggar made preliminary SNR calculations from these characteristics. Anticipated work consists of completing construction of the radiometer. Once completed, Biggar will test it and write control and data acquisition software.

The major problem encountered with the cross-calibration radiometer is lack of information. We have not received any information regarding the necessity of making the radiometer vacuum compatible. In order to prevent construction of the system from falling behind schedule, we have opted to build the current radiometer without vacuum compatibility. This system could still be converted to a vacuum design by turning the filter wheel assembly with a DC servo-motor with position encoders. Other portions of the radiometer would require expensive redesign as well. We have also received no information regarding whether interference filters from the same lot as those used for the satellite sensors will be available. We cannot make detailed SNR calculations until the filters are further specified.

REFLECTOMOBILE: The task objective is to design a vehicle to perform surface reflectance measurements more accurately and repeatably requiring only one person. In the past, people have carried yokes that extend the instrumentation away from the walker's body to reduce shadow and other problems. This method requires the involvement of at least three people, takes about 40 minutes to cover a 0.02 square kilometer site, and depends on the ability of the walker to orient the radiometer correctly. Because of the critical nature of these measurements, the idea of the reflectomobile was conceived. We planned to design, construct, and test the reflectomobile, as well as write data acquisition and processing software.

D. I. Gellman proposed several designs for the reflectomobile. Based on stability and weight considerations, Gellman selected a tetrahedral space frame attached to a trailer as the best, with a vehicle towing the trailer across the study site to collect data. Gellman selected a trailer low to the ground to reduce shadow problems but with large enough tires to provide ride stability. The university's main instrument shop machined parts unavailable through commercial avenues based on drawings supplied by Gellman. Gellman ordered all other parts and modified them when necessary. For initial assembly, Biggar and Gellman mounted the space frame to the trailer with C-clamps and drilled mounting holes in the trailer's frame. The university garage painted the trailer and space frame beige. Gellman measured the reflectance of this paint using a Barnes Modular Multiband Radiometer (MMR), and found it relatively flat out to 2.5 micrometers. A university owned Isuzu Trooper was selected as the tow vehicle and a hitch was attached to it (see Fig. 3 for photographs of the reflectomobile and tow vehicle). Biggar and Gellman tested the reflectomobile on a parking lot with speed bumps with good results. Lastly, Gellman wrote a preliminary version of the data acquisition software.

Further tests were performed at Rogers Dry Lake in California as part of a recent field experiment. The reflectomobile covered an 0.1 square kilometer area in 20 minutes, an eight-fold improvement over walking. Preliminary examination of the data collected over the five days indicates the reflectomobile behaved as expected. The most encouraging aspect, besides the time and manpower saved by the reflectomobile, is the greater measurement accuracy anticipated.

Several minor problems became apparent after the Rogers Dry Lake experiment. Some of the stresses on the trailer's wall were too great. Backing plates have been designed to reinforce the frame to alleviate this problem. Data acquisition software allowed some of the data to exceed the range of the datalogger causing a loss of data. Gellman will incorporate an auto-ranging feature to prevent this from occurring. There have also been problems with the serial port communications between the PC and the controller for the Spectron SE590, and solutions to this problem are being investigated. The height of the trailer hitch causes the trailer to tilt allowing the instruments to be off-nadir by as much as 5 degrees. To remedy this, we will either modify the hitch or swivel the instruments so they may be pointed perpendicular to the ground. The recent trip also indicated a need for characterizing atmospheric changes during the reflectance measurements by monitoring a reference panel with a second radiometer. Ideally, reference measurements should be collocated with the reflectomobile. We will examine the feasibility of such a system. These problems will be addressed in future work. Gellman plans to upgrade the acquisition software and to reinforce the trailer's frame at stress points. Exposed parts will be galvanized and painted, and we intend to develop a method for monitoring atmospherically-induced-irradiance fluctuations during reflectance measurements.

SWIR SPECTROMETER: The task objective of this project is to design and construct an instrument to measure surface reflectance in the SWIR region of the spectrum. When our contract began, M. W. Smith had already designed and built the prototype.

During this period, Smith measured the gain of the electronics, the full well capacity of the detector, and the dark current. He adjusted the gain of the electronics to match the range of the analog to digital (A/D) conversion electronics and synchronized these electronics with the array readout and shutter. A focussing mount for the fiber optic input and optional entrance slit were incorporated into the system. He received the following equipment: vibration resistant shutter, backpack frame for carrying the instrument (although it is also expected to be part of the instrumentation used on the reflectomobile), field-of-view optics, fiber-optic bundle, custom f/2 holographic diffraction grating, new dewar window, short-pass cold filter for reducing detector response to thermal radiation, electronic components, a long-pass filter for eliminating a detector memory effect, and interference filters for testing the quantum efficiency of the

detector. Smith developed the software necessary for spectral alignment, focussing, and calibration. Scan data collection software was written to collect data from a single scan or to average multiple scans. Smith also created software that provides output in a format appropriate for importing into a spreadsheet.

Smith completed the final design of all electronics and constructed 75% of the power supply, shutter control, temperature control hardware, array readout, A/D synchronization, and computer interfacing equipment. He designed and began constructing new cold stop baffles. A new mounting flange for thermally isolating the diffraction-grating housing from the detector and permitting more convenient spectral alignment was designed and is currently being built.

Smith performed spectral measurements using both a broad-band source (a tungsten-halogen lamp at 3200 K) and a discrete line source (a low pressure argon lamp). The discrete line source was used to spectrally calibrate the instrument with an average accuracy of 0.3 nm for wavelength-to-pixel assignment over the 1.1 to 2.5 micrometer SWIR range. Smith measured the system resolution (full-width at half-maximum) of an isolated spectral line as 12.3 nm, slightly worse than the computed value of 10.8 nm. Results from the broad-band source indicate the system behaves as predicted with system response decreasing with increasing wavelength.

Smith anticipates the design and construction of the field housing and other mechanical parts will be completed during the next six-month period. The entrance slit will be remachined to desired tolerances and Smith will construct and modify electrical and computer interface circuits. He will continue to carry out spectral calibration measurements as well as beginning radiometric calibrations. Measurements of the non-linear response, second order response, polarization sensitivity, field of view, and SNR will be performed. These measurements will be followed by field tests of the instrument.

Several problems became apparent during the six-month period. A detector memory effect due to radiation of wavelengths less than 1.1 micrometers was discovered. Smith eliminated this problem by using a silicon absorption filter. A non-linear effect, of which the manufacturer has admitted knowledge, was discovered. Smith will characterize this non-linear effect. The noise of the system was determined to be 5-10 times as large as predicted. Mostly electronic noise, due to poor shielding and filtering of the A/D conversion electronics inside the computer, causes this and increasing the shielding and filtering should correct it. There has been a delay in the delivery of filters for measuring the second-order response of the system, but this is not expected to cause trouble. The last problem encountered involves the sapphire end windows used to prevent moisture degradation of the fiber optic bundles. To date, one has chipped and another broken, indicating a susceptibility to breakage. As yet no firm solution

has been determined. Smith could eliminate the windows and accept the degradation of the bundles or use silica fiber optics. The silica fiber optics would give enhanced performance of the instrument, except in the 2.4 to 2.5 micrometer range.

BRDF METER: The task objective for this 6 month period was to design and begin construction of an instrument to describe quickly and accurately the BRDF of a surface. The design incorporates a fisheye lens and a CCD-array detector.

M. R. Brownlee purchased the fisheye lens, a Nikkor 8 mm, and examined its performance in both the visible and near infrared (NIR). She tested the resolution of the lens and the influence of the interference filters on its resolution. Candidate detector systems were investigated and the initial interference filters' specifications determined, based on studies performed by Brownlee. In these studies, she examined the shifts in central wavelength due to oblique angles of incidence. She also selected central wavelengths so as to minimize effects due to atmospheric absorption. The required out-of-band blocking required for the filters was determined using LOWTRAN7 calculations and desired SNRs.

Brownlee determined two possible locations for the interference filters in the system, the focal plane and the filter wheel which currently holds the absorption filters. By examining the effects of oblique angles of incidence, she determined that broadening of the bandpass and reduced transmission is negligible for filters of 50 nm bandwidths in either location. The largest estimated shift in central wavelength is 10.3 nm in the 760 to 900 nm range for a cone of light entering the edge of the lens. Because this is of similar magnitude for both locations, the current location of the filter wheel was selected for simplicity and cost.

Spatial resolution tests were performed on the lens by taking photographs of a bar chart. The camera was pointed downward from a height of 2 m and the bar chart placed at various distances from the camera setup. Brownlee took photographs in both the visible and NIR, using infrared black and white film, blocking the visible light with an absorption filter for the photographs in the NIR. Visual inspection of the photographs indicates that the CCD-area-array detector will be the limiting factor for system resolution.

Anticipated future work includes ordering the CCD-array detector system. This has been delayed so all possible systems may be properly examined to ensure selection of the best system. The initial set of interference filters will be ordered. Brownlee will determine the proper exposure settings for various sun angles and atmospheric conditions at well known sites (White Sands Missile Range, for example). She will also develop the calibration methodology, examine data storage methods, determine the best means of automating the retrieval process, and begin researching image processing of the data.

CARY SPECTROPHOTOMETER: The objective of this project is to refurbish a Cary 14 spectrophotometer for use in the laboratory. To date, J. M. Palmer has constructed the source assembly and completed the entrance optics. He designed and procured the majority of the drive system and put in place the short-wave detector system optics. The preamplifier and computerized control system design has been 80% completed, as well as 80% of the exit/sample optics design. Palmer identified appropriate spectral transmittance standards and necessary electronic components. He completed the mechanical wavelength drive, began work on the entrance slit, and designed the mechanical portion of the exit optics. It is anticipated that refurbishment and testing will be completed within the next 6-month reporting period. To date no problems have been encountered with this project.

ALGORITHM AND CODE DEVELOPMENT: This section is broken into two parts. The first part discusses work relating to the thermal infrared (TIR) portion of the spectrum. The second covers the algorithms and code used in the visible and NIR. In addition to the work stated below in these two areas, Thome wrote the preliminary version of the Software Data Management Plan and, based on information provided by Biggar, began writing the Science Computing Facilities plan.

A) TIR: Currently, several algorithms exist to perform work in the TIR portion of the spectrum. The task is then to determine which of these algorithms best fits the current problem. Palmer conducted a thorough search of the literature of these methods and is in the process of determining which is the most appropriate. He used LOWTRAN7 to determine the limits of the problem and rebuilt a TIR thermometer for use in field work validation. A radiometer was located for preliminary emittance measurements and commercially available radiometers were surveyed and narrowed to a list of three. Future work includes designing the TIR blackbody used for ground emittance studies. Further LOWTRAN7 work will be performed and Palmer will acquire the new TIR radiometer and data acquisition equipment. This portion of algorithm development is still in the early stages and no problems have been encountered.

B) Visible and NIR: Currently, several algorithms exist to perform work in this portion of the spectrum. The RSG has applied these algorithms as FORTRAN programs which are neither user friendly nor efficiently linked together into a single package. The task objective is to begin converting these existing codes into ANSI standard C. The first of these programs to be converted is the Langley method program which determines zero-airmass intercepts for our solar radiometers as well as total and Rayleigh optical depths.

Thome converted the Langley program to C. He adjusted the algorithm slightly to perform the straight-line fit to the signal adjusted for Rayleigh scattering. A rules-based method for

rejecting bad data points was developed. This method removes those points for which rapid changes in optical depth occur, which are typically due to operator error or cloud contamination. Thome also developed a method for tracking the zero-airmass intercept of the instrument and routines for determining the randomness of the data. Randomness is tested through a pair of statistical-runs tests, which help indicate systematic changes in optical depth during the measurement period.

Thome and H. He also modified algorithms and programs related to water vapor retrieval and radiative transfer calculations. Thome refined the algorithm for determining columnar water vapor from solar radiometer measurements and began examining techniques for incorporating this algorithm within the Langley method program. The radiative transfer program was modified to allow arbitrary solar and view zenith angles, to incorporate surface BRDF effects, and to simplify usage. Thome also wrote a preliminary version of a user's guide for operating the program in a stand-alone configuration. H. He then converted the code from FORTRAN to ANSI standard C. She also began work developing image processing software for the UNIX-based Sun environment. This work included investigating image display software for our Sun network and developing image-tape-reading software.

Results from the newly developed Langley method program were compared to the FORTRAN version by examining four days of data collected from early June of this year processed using both programs. Very little difference was found between the retrieved intercepts from the two programs, indicating no serious programming errors in the new version. The variance of the least-squares fits was reduced by as much as 50% by removing effects due to Rayleigh scattering before determining the zero-airmass intercept. This effect decreased with wavelength as expected. Data sets were collected during a recent field experiment at Rogers Dry Lake on days that were clearly unsuitable for the Langley method. These data will test the rules-based method of intercept averaging still in development.

Anticipated actions during the next six-month period include development of the rules-based method for selecting the appropriate average zero-airmass intercept. An algorithm and code will be developed to improve results from marginal data sets by removing highly variable portions of the data. Thome will implement the columnar water vapor retrieval within the Langley method program and link the Langley method program to an aerosol and ozone optical depth retrieval program. The program to compute the aerosol size distribution from optical depths will be converted and linked to the Langley program. H. He will continue developing image display software and begin examining code used to collocate satellite images from two separate satellites. To date no problems have been encountered.

FIELD EXPERIMENTS: The objectives of the field experiments are to test new equipment, indicate needed improvements, test retrieval

algorithms and code, and monitor existing satellites in much the same way as we shall for Eos sensors. During the six-month period, the RSG made two trips. The group also provided data support to M. S. Moran of the U. S. Water Conservation Lab as part of her project in the Walnut Gulch watershed in Arizona.

In March, Biggar, Gellman, and Thome, accompanied by Moran and T. R. Clarke of the U. S. Water Conservation Lab and S. L. Ustin of UC Davis travelled to White Sands Missile Range. Unfortunately, poor weather prevented any useful data from being collected. We did, however, test several modifications of the data retrieval program.

At the end of May, Biggar, Gellman, Slater, and Thome, accompanied by R. Santer of the University of Lille, travelled to Edwards Air Force Base in California to take data over Rogers Dry Lake. This trip marked the initial test of the reflectomobile. The group also collected data to calibrate the HRV sensors of SPOTs 1 and 2, and supported the Jet Propulsion Laboratory by providing AVIRIS calibrations.

Gellman performed a study of past SPOT-2 calibrations by determining the best position of on-board-lamp-calibration curves relative to ground-based data points. He obtained different results depending upon the weight given to each of the ground-based points and the method of fitting the lamp curves. These results were presented to M. Dinguirard of CERT and P. Henry of CNES

during a recent visit to the University of Arizona. Also presented during this visit were results shown by R. D. Jackson indicating an apparent bias in radiances obtained from airplane measurements. These two topics are currently being investigated.

Future work will center around upgrading and recalibrating equipment and planning for future field experiments. The reflectomobile will be modified as stated earlier and a parasol used to block the direct solar beam for diffuse reflectance measurements will be designed and built. We will modify software for reflectomobile data retrieval as well as modifying the Spectron control program. We plan to recalibrate our Barnes MMR, Fluke datalogger, barometer, solar radiometer, HP digital voltmeter and power supplies, and Leeds and Northrup shunt box. Future trips are planned to White Sands, Maricopa Agricultural Center, and Walnut Gulch.

Figure Captions

Figure 1. ASTER laboratory signal-to-noise ratio as a function of ground reflectance for several gain settings

Figure 2. Percentage change in band-averaged solar irradiance due to shifts in central wavelength. Top graph shows percentage change due to a 1.2 nm shift towards the blue end of the spectrum for various center wavelengths and bandpasses. Lower graph shows change as a function of shift for a center wavelength of 488 nm and various bandpasses.

Figure 3. Photographs showing reflectomobile and tow vehicle. Attached to the extended arm of the space frame is a Barnes MMR. Counterweights are attached to the other side.

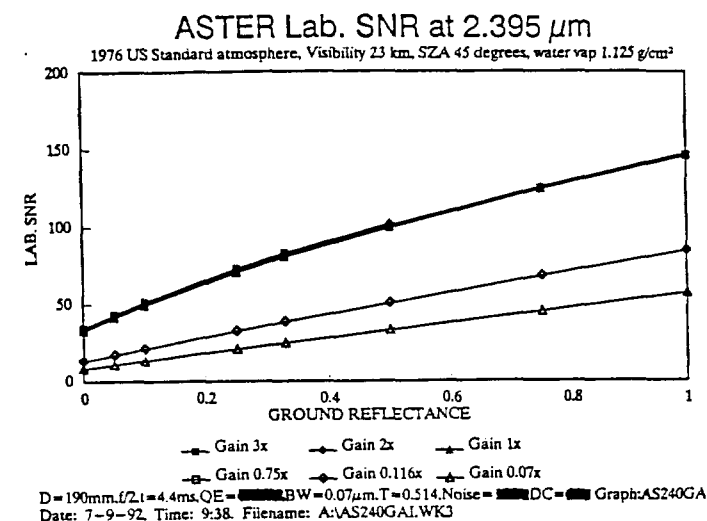
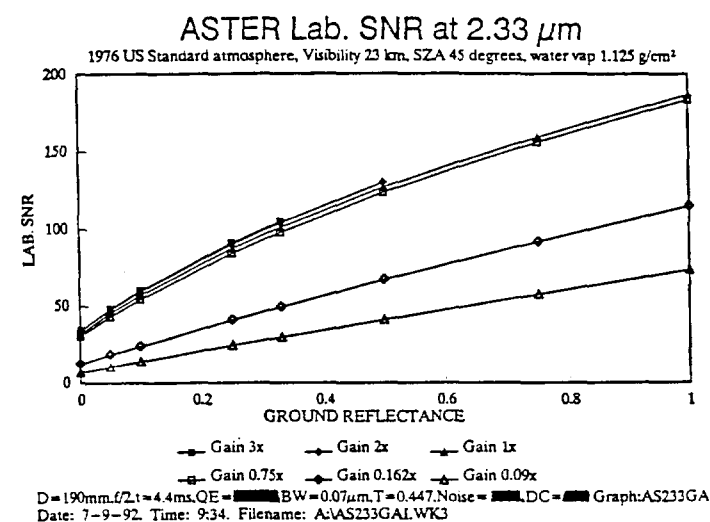
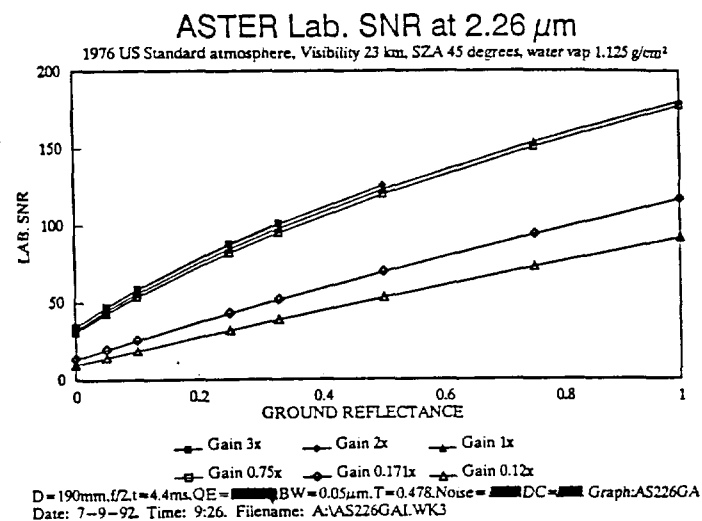
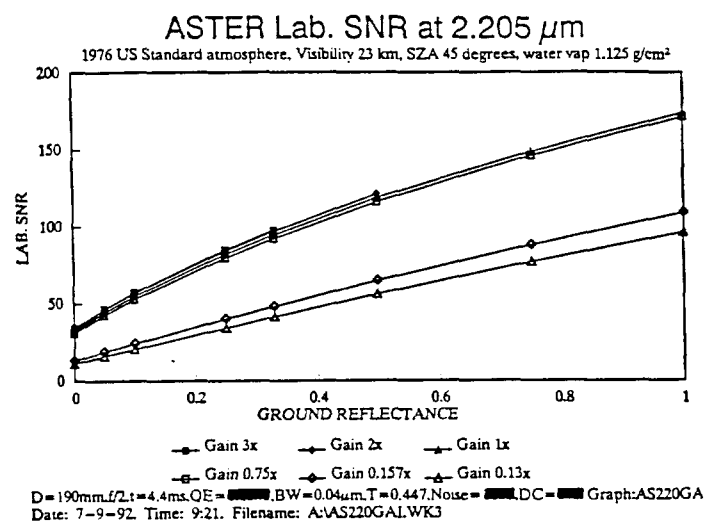
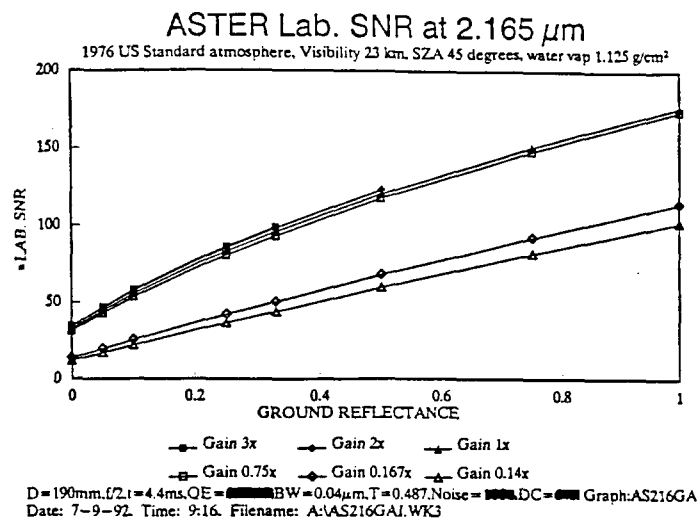
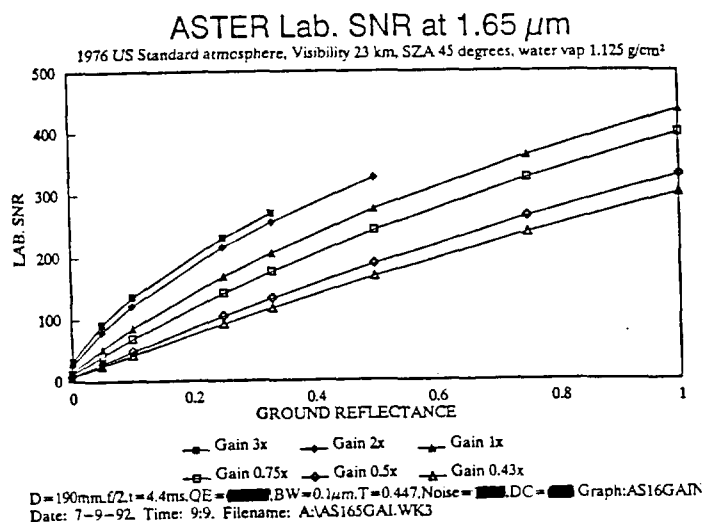


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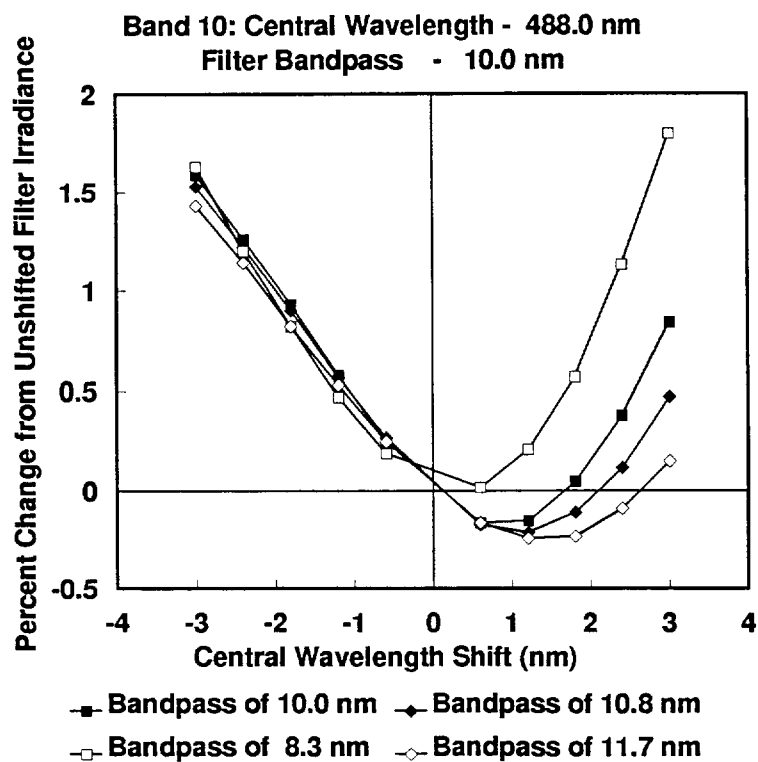
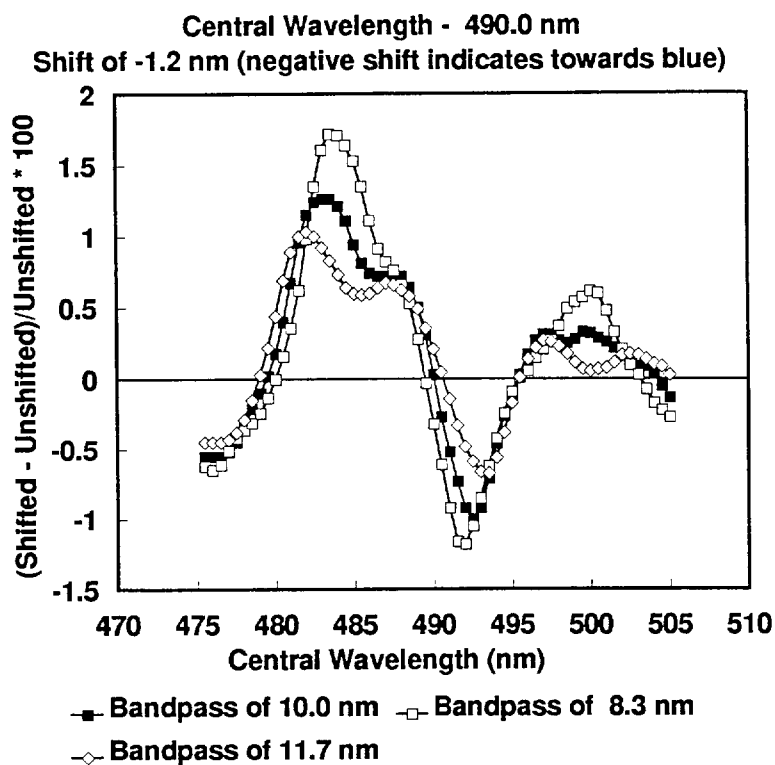


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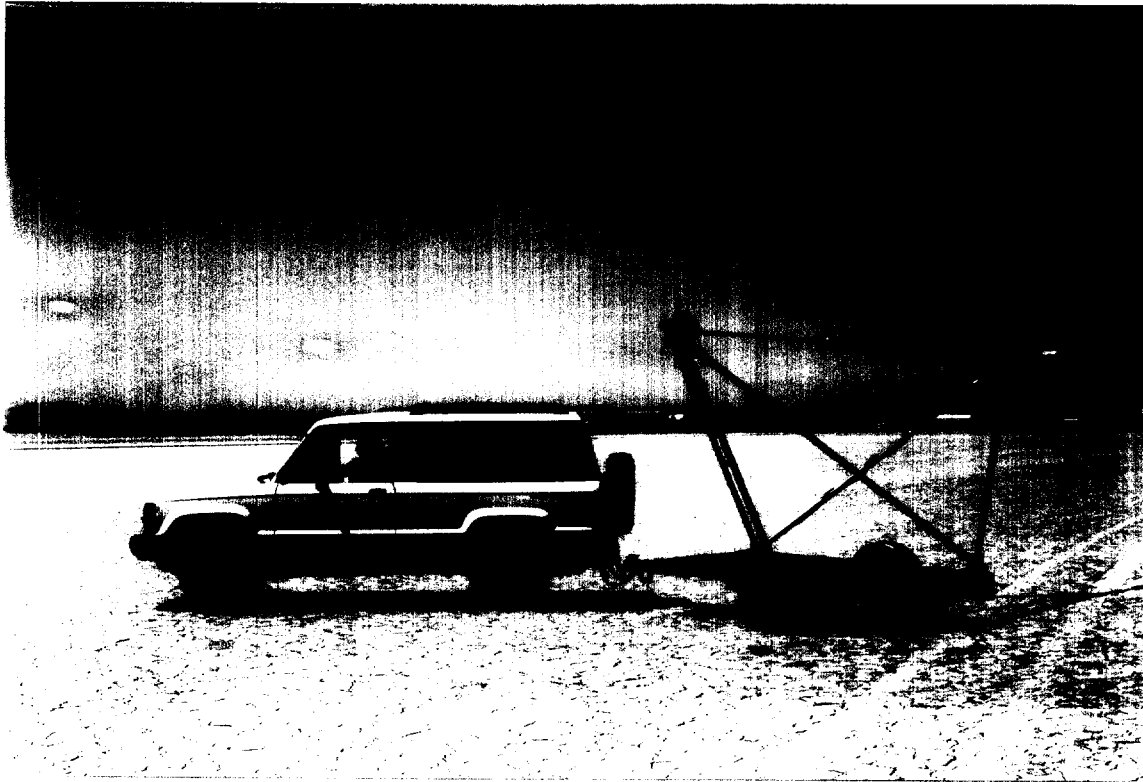


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